

CONF-8906241--1

CONF-8906241--1

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DEMONSTRATION OF A COMPUTER MODEL FOR RESIDUAL
RADIOACTIVE MATERIAL GUIDELINES, RESRAD

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ABSTRACT

A computer model was developed to calculate residual radioactive material guidelines for the U.S. Department of Energy (DOE). This model, called RESRAD, can be run on an IBM or IBM-compatible microcomputer. Seven potential exposure pathways from contaminated soil are analyzed, including external radiation exposure and internal radiation exposure from inhalation and food ingestion. The RESRAD code has been applied to several DOE sites to derive soil cleanup guidelines. The experience gained indicates that a comprehensive set of site-specific hydrogeologic and geochemical input parameters must be used for a realistic pathway analysis. The RESRAD code is a useful tool; it is easy to run and very user-friendly.

and data for deriving site-specific soil guidelines are provided in a report entitled *A Manual for Implementing Residual Radioactive Material Guidelines*.² These procedures and data are coded in a microcomputer model called RESRAD.

ENVIRONMENTAL PATHWAYS

The RESRAD model calculates the potential radiation doses resulting from seven potential exposure pathways: (1) direct exposure to external radiation from contaminated soil materials, (2) internal radiation from inhalation, (3) internal radiation from ingestion of plant foods grown on-site and irrigated with water drawn from an on-site well or pond, (4) internal radiation from ingestion of meat from livestock fed with fodder grown on-site and water drawn from an on-site well or pond, (5) internal radiation from ingestion of milk from livestock fed with fodder grown on-site and water drawn from an on-site well or pond, (6) internal radiation from ingestion of aquatic foods (fish) from a nearby pond, and (7) internal radiation from drinking water from an on-site well or pond. If certain pathways are considered to be negligible or not contributing to the total dose, they can be eliminated by setting certain parameters to zero in the RESRAD code.² The theoretical basis, calculational models, and data bases for RESRAD are described in detail in References 2 and 3.

INTRODUCTION

The U.S. Department of Energy (DOE) has established radiological protection guidelines for cleanup of residual radioactive material located at sites administered under its Formerly Utilized Sites Remedial Action Program (FUSRAP) and Surplus Facilities Management Program (SFMP).¹ The guidelines establish radionuclide concentrations or radioactivity levels that are acceptable if the site is to be used without radiological restrictions. Guidelines can be categorized as either (1) generic (or site-independent), i.e., taken from existing radiation protection standards, or (2) site-specific, i.e., derived from the basic dose limit (100 mrem/yr) using site-specific models and data. Generic guidelines for radium-226, radium-228, thorium-230, and thorium-232 are presented in Reference 1. For other radionuclides, procedures

PROGRAM DESCRIPTION AND REQUIREMENTS

The RESRAD model was developed for use on an IBM or IBM-compatible personal computer. The program is designed with various user-friendly features, including internal help files for information on input and output data, with an optional mouse to show default data values. A DOS 3.1 or equivalent operating system, a hard disk drive, and approximately 400K of memory are required to run RESRAD; a mathematics coprocessor is optional but highly recommended.

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MASTER

RESRAD consists of two main programs, RESPC and RESMAIN. RESPC is a compiled Basic program (Microsoft QuickBASIC 4.5) that handles all user interaction with RESRAD, and RESMAIN is the Fortran code (Lahey F77L, Ver. 3.01) that does the actual computations and generates the output tables.

RESPC is loaded first (via RESRAD.BAT, NEXT.ORI, and NEXT.BAT). Within RESPC, the user may input selected site-specific data files, review and/or modify the parameters, save the data in a selected file, view and/or print selected results from the last RESMAIN computation, and run RESMAIN for a new computation. If RESMAIN is called, RESPC is reloaded automatically when RESMAIN completes, and the user may continue with any of the RESPC options.

To conserve memory, RESMAIN is organized with an overlay structure. The code is highly optimal in that no overlay is called a second time. PLINK86plus, Ver. 2.24, Phoenix Technologies Ltd., is the overlay linkage editor used.

MAIN MENU

The main menu (R010), as shown in Figure 1, is the starting point for using RESRAD. It is also the return point after completion of RESRAD's calculation phase. By selecting the major data and function categories, all input data and output reports are accessible from the main menu. To terminate RESRAD, press "Esc" while the main menu is on screen.

Instructions for interactive use of the code are provided in help files that can be displayed on the screen by pressing the "F1" or "F2" function key. Menu items are selected in the

main menu (R010) by entering the appropriate item number and pressing "Enter." Items 1-9 display input forms on the screen, item 10 calculates results for the current set of parameters, and item 11 displays the output (summary or detailed report) from the last RESRAD run, or the user may view any selected ASCII file.

INPUT FORMS

Input data needed by RESRAD are accessible in a series of input forms. Figures 2-10 show the RESRAD input menus corresponding to items 1-9 on the main menu (see Figure 1). The input data shown on the input menus are the default data used in RESRAD. After an input form has been called for display, its input data can be reviewed and changed from the terminal. Pressing the "F10" function key will record all displayed entries and return control to the main menu. The changes made after an input form has been modified (but before it has been recorded) can be canceled by pressing the escape ("Esc") key. Recorded data are retained until changed again.

EXECUTION AND OUTPUT OPTIONS

When option 10 of the main menu is selected, RESRAD enters its RESMAIN computation and report generation phase. After RESMAIN execution is completed, the main menu (R010) will appear on the screen, and the user may continue with any of the options. However, the customary course will be to examine the output reports just generated via main menu option 11.

When option 11 is selected, the user is prompted to select for viewing the summary or detailed report from the last RESRAD run or any ASCII file. The last option is particularly

```
RESRAD: Residual Radioactive Material Program (R010)
-----
RESRAD Main Menu
-----
You may now access specific RESRAD data, or you may run the RESRAD code.

----- Major Data and Function Categories -----
1. Title, user data files, and contaminated zone parameters
2. Initial concentrations of principal radionuclides
3. Contaminated zone hydrological data
4. Saturated zone hydrological data
5. Uncontaminated and unsaturated strata hydrological data
6. Distribution coefficients and leach rates
7. External gamma and dust inhalation parameters
8. Ingestion pathway data, dietary parameters
9. Ingestion pathway data, nondietary parameters

10. Execute the code

11. View latest RESRAD output (or any ASCII file)
-----
Enter 1-11 from above list to select data or function category: 
Or press "F1" or "F2" for HELP, or "Esc" to EXIT from RESRAD system.
```

FIGURE 1 Main Menu for RESRAD

useful for examining saved output from a prior RESRAD run. It should be noted that it is not necessary to execute RESRAD (or, more strictly, RESMAIN) before using option 11. In general, SUMMARY.REP and DETAILED.REP files from the last RESRAD run will be available and may be examined at any time. However, if appropriate, the user will be warned that the report file may not match the current site-specific data file.

Summary Report

When the summary report option is selected, the first page (table of contents) of a multiple page summary report is displayed on the screen. The table of contents is shown in Figure 11. Subsequent report pages can be displayed by entering the page number and pressing either the "Enter" or "F10" function key. Pressing "Esc" will return to the main menu, R010. On-line help, primarily key strokes to aid in the page display, is available via the "F1" function key. Function keys "F7" and "F8" can be used to produce hard copy output.²

Detailed Report

When the detailed report option is selected, the first page (table of contents) of a multipage detailed report is displayed on the screen. A typical table of contents is shown in Figure 12. Individual report pages can be displayed and printed (or saved) in the same manner as for the summary output displays. The detailed displays present all of the intermediate calculation results. Users will not normally make use of these tables. The detailed data are used for verifying the code and can be useful for gaining insight into the transport mechanisms by enabling a more detailed investigation of the effect of parameter changes on pathway factors, environmental transport factors, and dose/source ratios for the different pathways.

DISCUSSION AND CONCLUSIONS

A computer program called RESRAD has been developed for DOE to calculate site-specific residual radioactive material guidelines for FUSRAP and SFMP sites. The code calculates potential radiation doses to individuals resulting from various potential exposure pathways. RESRAD is menu-driven with help files and built-in features to facilitate data manipulations. It is easy to install and can be run on an IBM or IBM-compatible microcomputer.

The RESRAD code has been applied to derive soil cleanup guidelines for several FUSRAP sites currently being decontaminated.⁴⁻⁶ The code is a useful tool, easy to run, and very user-friendly.

ACKNOWLEDGMENT

Work supported by the U.S. Department of Energy, Assistant Secretary for Nuclear Energy, under Contract W-31-109-Eng-38.

REFERENCES

1. U.S. Department of Energy, 1987, *U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites* (Revision 2, March 1987).
2. Gilbert, T.L., et al., 1989, *A Manual for Implementing Residual Radioactive Material Guidelines*, ANL/ES-160; DOE/CH/8901, prepared by Argonne National Laboratory for U.S. Department of Energy (June).
3. Yu, C., Y.C. Yuan, A.J. Zielen, and A. Wallo III, 1989, *Residual Radioactive Material Guidelines: Methodology and Applications*, Waste Management '89, Proceedings of Symposium, Tucson, Ariz., Feb. 26 - March 2, Vol. II, pp. 633-639.
4. Yu, C., J.M. Peterson, and Y.C. Yuan, 1988, *Derivation of Uranium and Cesium-137 Residual Radioactive Material Guidelines for the Niagara Falls Storage Site*, prepared by Argonne National Laboratory for U.S. Department of Energy (Aug.).
5. Yu, C., J.M. Peterson, and Y.C. Yuan, 1988, *Derivation of Uranium Residual Radioactive Material Guidelines for the Ashland 1 and 2 Sites*, prepared by Argonne National Laboratory for U.S. Department of Energy (Aug.).
6. Boggs-Mayes, C., and C. Yu, 1989, *Derivation of Uranium Residual Radioactive Material Guidelines for the Three St. Louis FUSRAP Sites: St. Louis Downtown Site, St. Louis Airport Site, and Latty Avenue Properties*, prepared by Argonne National Laboratory for U.S. Department of Energy (Jan.).

RESRAD: Residual Radioactive Material Program (R011)

Title, User Data Files, and Contaminated Zone Parameters

You may now view or modify any of the following parameters.

Title: RESRAD_Sampla Data

Site-specific data file (initial): RESRAD.DEF
 Site-specific data file (final): SAMPLE.DAT
 Printer output (LPT1 or file): LPT1

Area of contaminated zone: 10000 square meters
 Thickness of contaminated zone: 1 meters
 Length parallel to aquifer flow: 100 meters

Basic radiation dose limit: 100 millirem/year

Times for calculations: 1 10 100 1000 10000 0 0 0 0
 (years since initial time, 32767 is maximum)

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
 Press "F10" to SAVE DATA AND CONTINUE.

FIGURE 2 Input Form R011 for Title, User Data Files, and Contaminated Zone Parameters

RESRAD: Residual Radioactive Material Program (R012)

Initial Concentrations of Principal Radionuclides

Radionuclide	Si(0) (pCi/g)	Radionuclide	Si(0) (pCi/g)	Radionuclide	Si(0) (pCi/g)
Ac-227+D	0	Am-241	0	Am-243+D	0
C-14	0	Cm-243	0	Cm-244	0
Co-60	0	Cs-135	0	Cs-137+D	0
Eu-152	0	Eu-154	0	Fe-55	0
K-3	0	I-129	0	Nb-94	0
Ni-59	0	Ni-63	0	Np-237+D	0
Pa-231	0	Pb-210+D	0	Pu-238	0
Pu-239	0	Pu-240	0	Pu-241	0
Pu-242	0	Ra-226+D	0	Ra-228+D	0
Sm-151	0	Sr-90+D	0	Tc-99	0
Th-228+D	0	Th-229+D	0	Th-230	0
Th-232	0	U-232	0	U-233	0
U-234	1	U-235+D	0	U-236	0
U-238+D	1				

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
 Press "F10" to SAVE DATA AND CONTINUE.

FIGURE 3 Input Form R012 for Initial Concentrations of Principal Radionuclides

RESRAD: Residual Radioactive Material Program (R013)

Cover and Contaminated Zone Hydrological Data

Cover depth: 0 meters
 Density of cover material: 1.6 grams/cubic centimeter
 Cover erosion rate: .001 meters/year

Density of contaminated zone: 1.6 grams/cubic centimeter
 Contaminated zone erosion rate: .001 meters/year
 Contaminated zone total porosity: .4
 Contaminated zone effective porosity: .2
 Contaminated zone hydraulic conductivity: 10 meters/year
 Contaminated zone b parameter: 5.3

Evapotranspiration coefficient: .6
 Precipitation: 1 meters/year
 Irrigation: .2 meters/year
 Irrigation mode: 0 (0 for overhead; 1 for ditch)
 Runoff coefficient: .2
 Watershed area for nearby stream or pond: 1000000 square meters

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
 Press "F10" to SAVE DATA AND CONTINUE.

FIGURE 4 Input Form R013 for Cover and Contaminated Zone Hydrological Data

```

RESRAD: Residual Radioactive Material Program (R014)
-----
Saturated Zone Hydrological Data
-----
You may now modify any of the following hydrological parameters.

Density of saturated zone: 1.6 grams/cubic centimeters
Saturated zone total porosity: .4
Saturated zone effective porosity: .2
Saturated zone hydraulic conductivity: 100 meters/year
Saturated zone hydraulic gradient: .02
Saturated zone b parameter: 5.3 (only if WTDR .NE. 0)

Distance from surface to water table: 5 meters
Water table drop rate (WTDR): .001 meters/year
Well pump intake depth: 10 meters below water table
-----
Model for Water Transport Parameters
-----
Nondispersion or Mass-Balance: 0 (0 for ND, 1 for MB)
Individual's use of groundwater: 150 m**3/year (only if MB)

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
Press "F10" to SAVE DATA AND CONTINUE.

```

FIGURE 5 Input Form R014 for Saturated Zone Hydrological Data

```

RESRAD: Residual Radioactive Material Program (R015)
-----
Uncontaminated and Unsaturated Zone Hydrological Data
-----
You may now modify the following hydrological parameters
for the unsaturated zone below the contaminated zone.

Set the thickness to > 0 to establish a stratum, or
set the thickness = 0 to delete the stratum and erase all data.

-----
Unsaturated Strata
-----
      1      2      3      4      5
Thickness (meters): 4
Soil density (grams/cubic cm): 1.6
Total porosity: .4
Effective porosity: .2
Soil-specific b parameter: 5.3
Hydraulic conductivity (meters/year): 100

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
Press "F10" to SAVE DATA AND CONTINUE.

```

FIGURE 6 Input Form R015 for Uncontaminated and Unsaturated Zone Hydrological Data

```

RESRAD: Residual Radioactive Material Program (R016)
-----
Distribution Coefficients and Leach Rates
-----
You may now modify any of the following parameters.

Distribution Coefficients (cm**3/g)
(** prefix on nuclide shows decay product only)

Zone      U-234      U-238      *Pb-210      *Ra-226      *Th-230
-----
Contaminated  50      50      100      70      60000
Unsaturated 1  50      50      100      70      60000
"           2
"           3
"           4
"           5
Saturated    50      50      100      70      60000

Leach rates
(year**-1): 0 0 0 0 0
Press "F5" (or "F6") to view previous (or next) 7 radionuclides.
Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
Press "F10" to SAVE DATA AND CONTINUE.

```

FIGURE 7 Input Form R016 for Distribution Coefficients and Leach Rates

```

RESRAD: Residual Radioactive Material Program (R017)
-----
External Gamma and Dust Inhalation Parameters
-----
You may now modify any of the following parameters.

Inhalation rate: 8400 cubic meters/year
Mass loading for inhalation: .0002 grams/cubic meter
Occupancy and shielding factor (external gamma): .6
Occupancy factor (inhalation): .45
Shape factor (external gamma): 1
Height of mixing for airborne dust (inhalation): 2 meters

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
Press "F10" to SAVE DATA AND CONTINUE.

```

FIGURE 8 Input Form R017 for External Gamma and Dust Inhalation Parameters

```

RESRAD: Residual Radioactive Material Program (R018)
-----
Ingestion Pathway Data, Dietary Parameters
-----
You may now modify any of the following parameters.

Fruits, vegetables and grain consumption: 160 kilograms/year
Leafy vegetable consumption: 14 kilograms/year
Milk consumption: 92 liters/year
Meat and poultry consumption: 63 kilograms/year
Fish consumption: 5.4 kilograms/year
Other aquatic food consumption: .9 kilograms/year
Drinking water intake: 410 liters/year
Fraction of drinking water from site: 1 (0-1)
Fraction of aquatic foods from site: .5 (0-1)

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
Press "F10" to SAVE DATA AND CONTINUE.

```

FIGURE 9 Input Form R018 for Ingestion Pathway, Dietary Parameters

```

RESRAD: Residual Radioactive Material Program (R019)
-----
Ingestion Pathway Data, Nondietary Parameters
-----
You may now modify any of the following parameters.

Livestock fodder intake for meat: 68 kilograms/day
" " " " milk: 35 kilograms/day
Livestock water intake for meat: 50 liters/day
" " " " milk: 160 liters/day

Mass loading for foliar deposition: .0001 grams/cubic meter
Depth of soil mixing layer: .15 meters
Depth of roots: .9 meters

-----
Groundwater Fractional Usage (balance from surface water)
-----
Drinking water: 1 (0-1)
Livestock water: 1 (0-1)
Irrigation: 1 (0-1)

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
Press "F10" to SAVE DATA AND CONTINUE.

```

FIGURE 10 Input Form R019 for Ingestion Pathway, Nondietary Parameters

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

Site-Specific Parameter Summary 2
 Contaminated Zone and Total Dose Summary 5
 Total Dose Components

Time = 0	6
Time = 1	7
Time = 10	8
Time = 100	9
Time = 1000	10
Time = 10000	11

Dose/Source Ratios and Radionuclide Soil Guidelines 12

FIGURE 11 Typical Table of Contents for Summary Report

Table of Contents

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Iteration Log#

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FIGURE 12 Typical Table of Contents for Detailed Report